# PV Inverter System-Level Reliability

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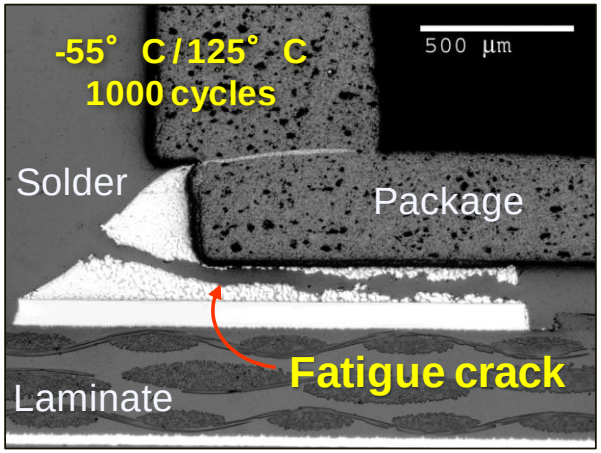
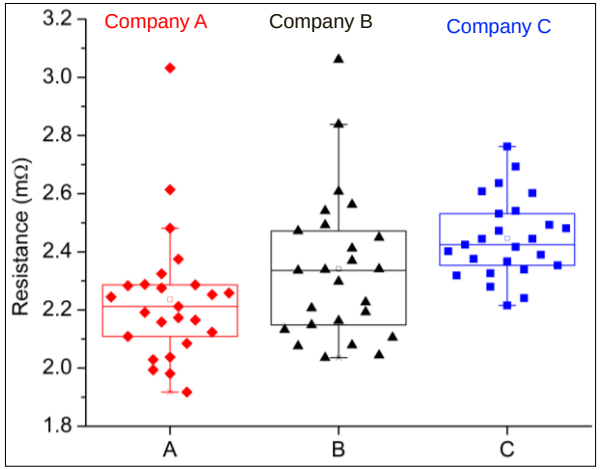
# Sandia PV Reliability Program

PV reliability program spans the spectrum from materials to systems

Focus on Balance of Systems (BOS)




Solder Joint Degradation




Connector Reliability

Inverter Thermal Performance

Advanced Inverter Function

Ground Fault
Arc Fault

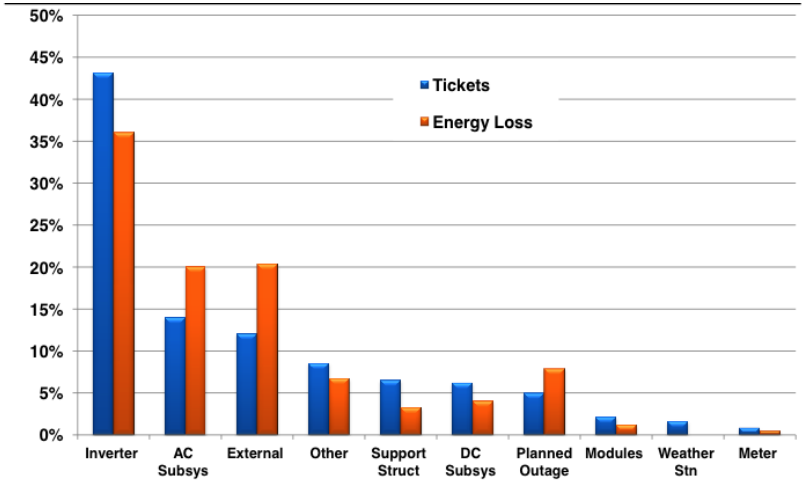
Materials | Components | Sub-system | System

Capacitor, IGBT, WBG

Flicker

# PV Inverter Introduction

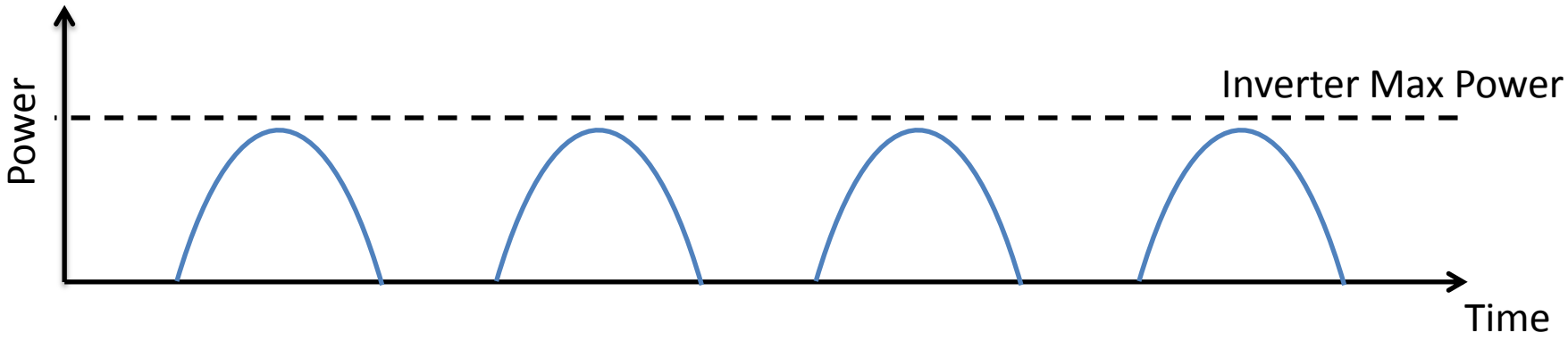
- DC/AC Conversion
  - Maximum power transfer
  - Power quality
- Many various topologies
  - Single/multi-stage
  - Isolated/non-isolated
  - single-/three-phase
- 3 major classes (3 orders of magnitude):
  - 500 kW (utility scale)
  - 5 kW (residential scale)
  - 250 W (microinverter)




A. Golnas, "PV System Reliability: An Operator's Perspective," PVSC, 2012


- Must endure harsh environments (humidity, corrosive) with large temperature cycles (ambient and power handling)
- Inverters are complicated machines
  - Variable Irradiance/Temperature
  - Power Conditioning
  - Grid Monitoring
  - Array reporting/monitoring
  - VAR management
  - Islanding protection, etc.
- Current trends in PV industry will push limits of inverter reliability

# Future of Inverter Reliability
# High DC/AC Ratios

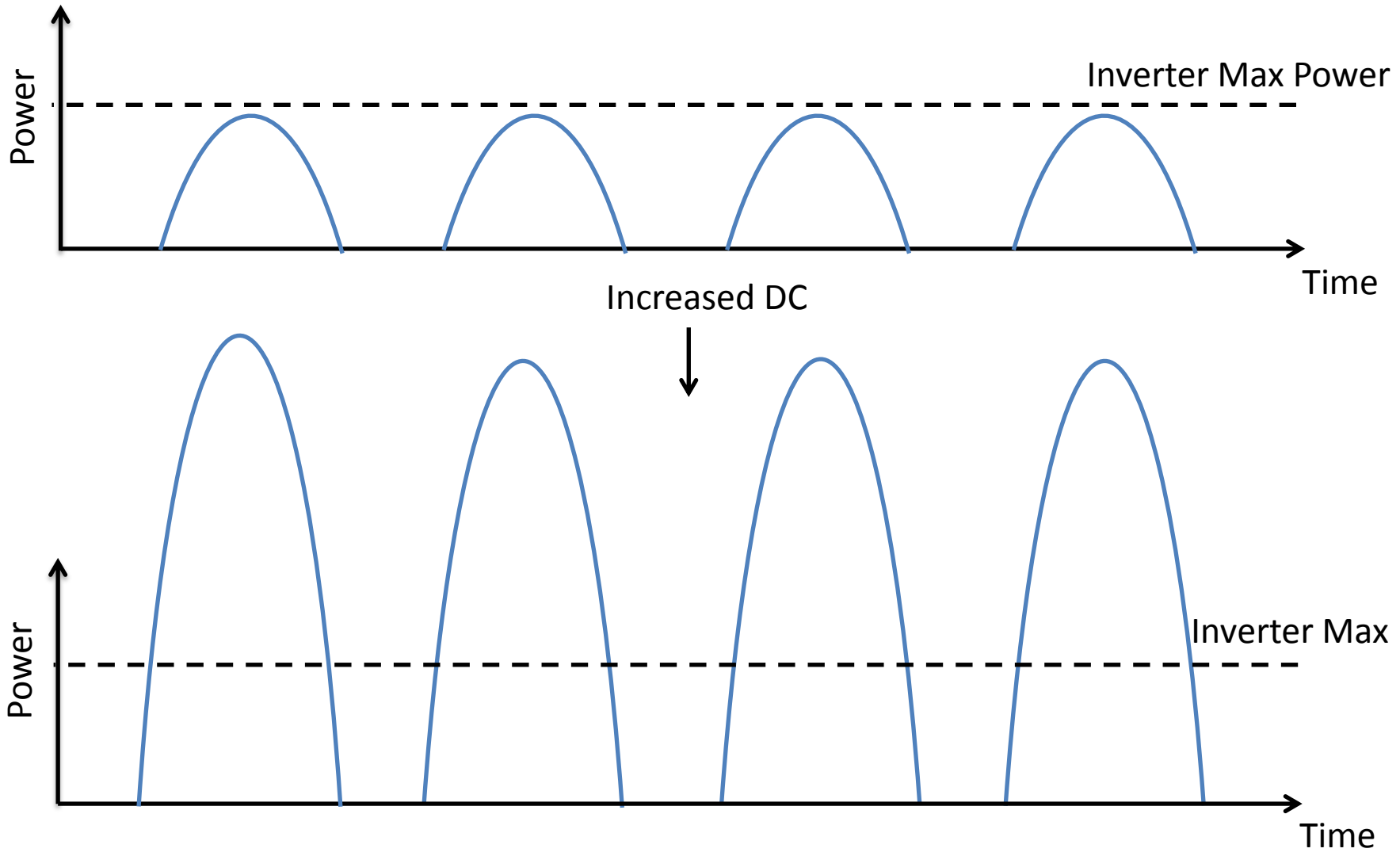



- PV plants can/do experience **high variability** during peak daytime hours
  - →High power demand (air conditioning)
  - →Difficult to predict supply, so cannot match demand

- Utilities value **consistency** as much as **power generation** capability

- As panel prices decrease, wasted DC power less important
- Can make PV more **consistent** by increasing DC:AC ratio

# Future of Inverter Reliability
# High DC/AC Ratios



# Future of Inverter Reliability
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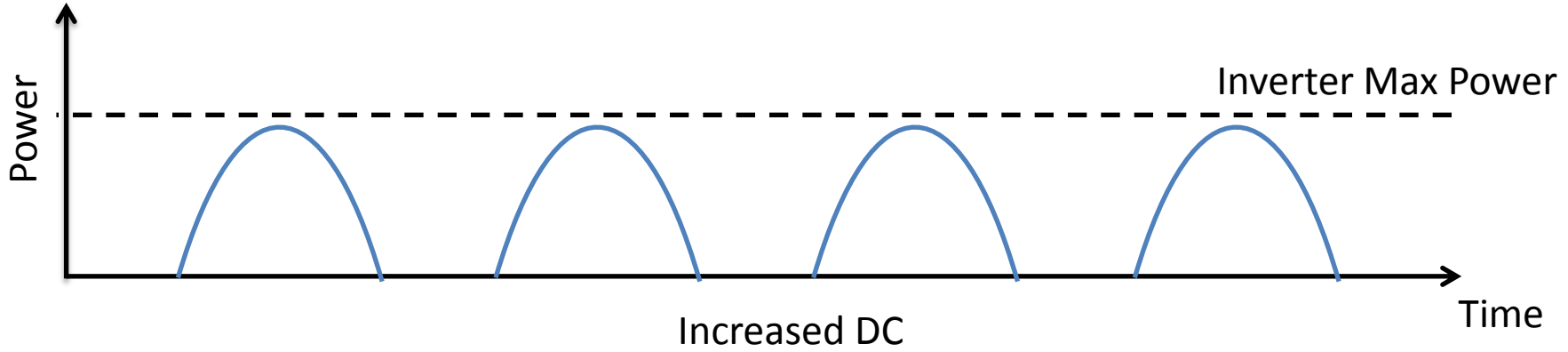
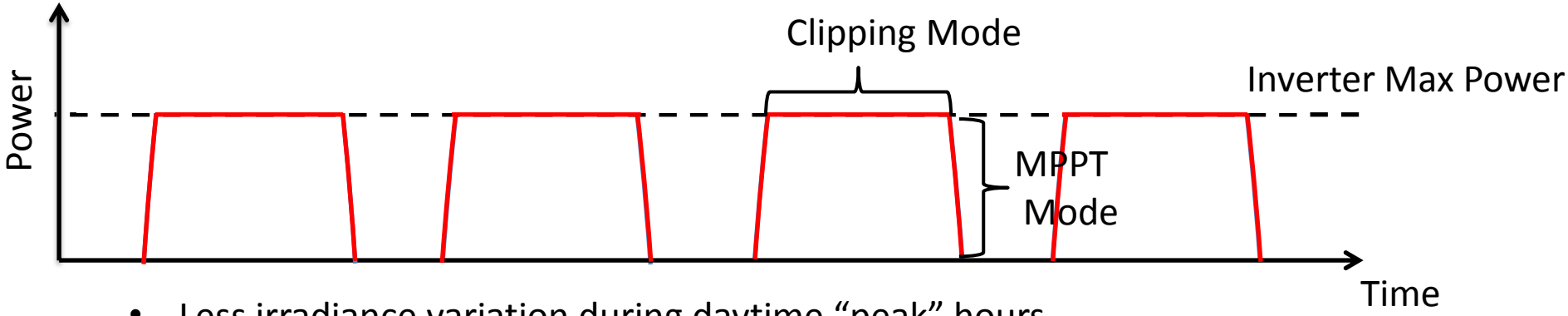
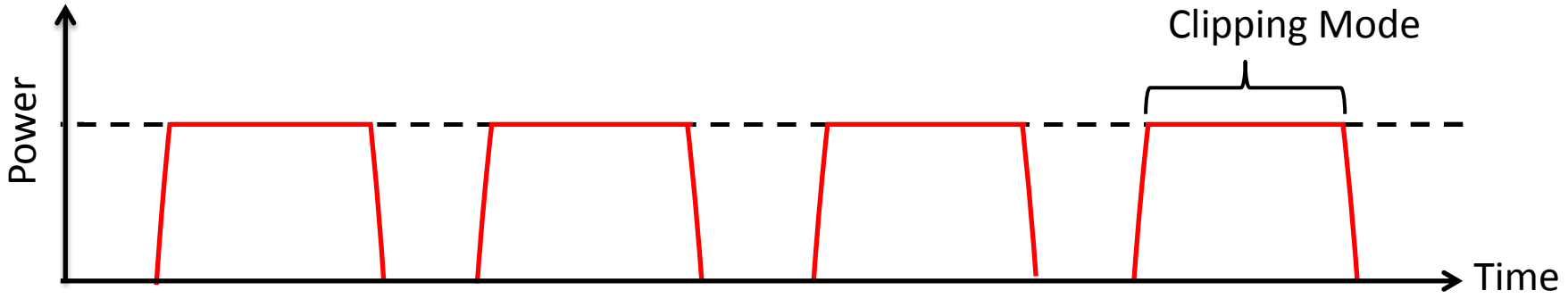
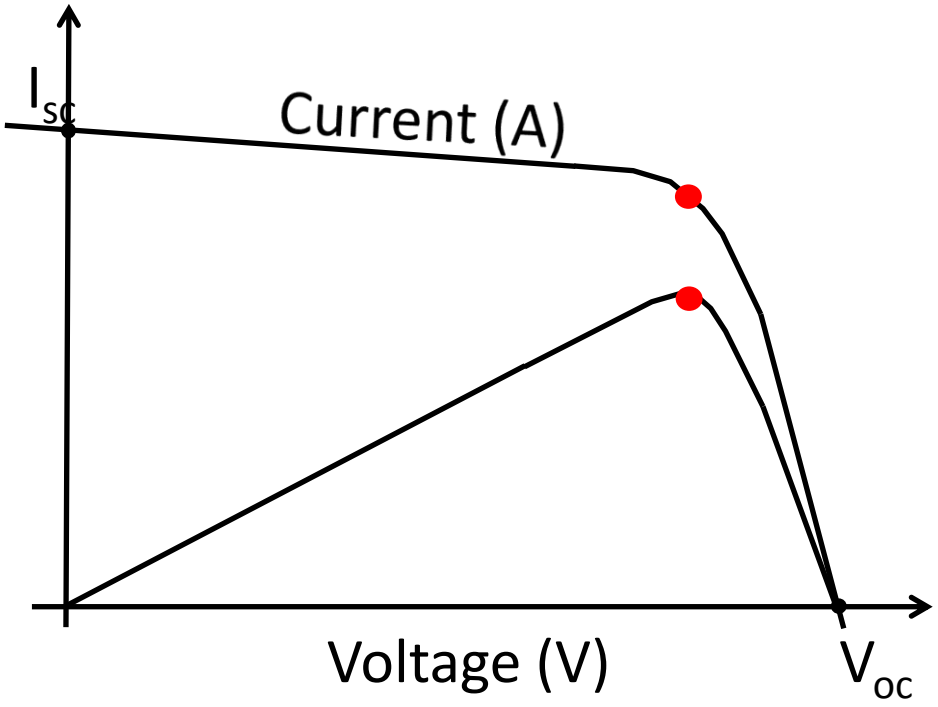



- Less irradiance variation during daytime “peak” hours
- Power output profile looks more like base generation

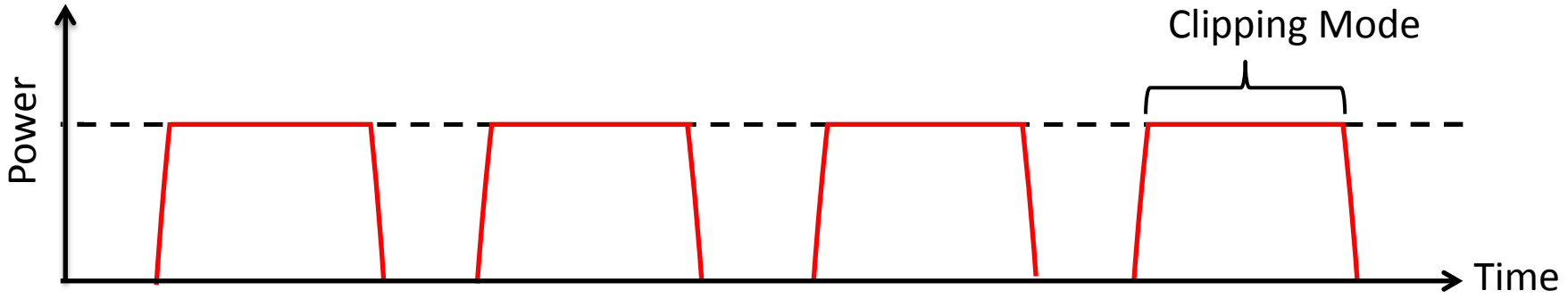
# Future of Inverter Reliability
# High DC/AC Ratios

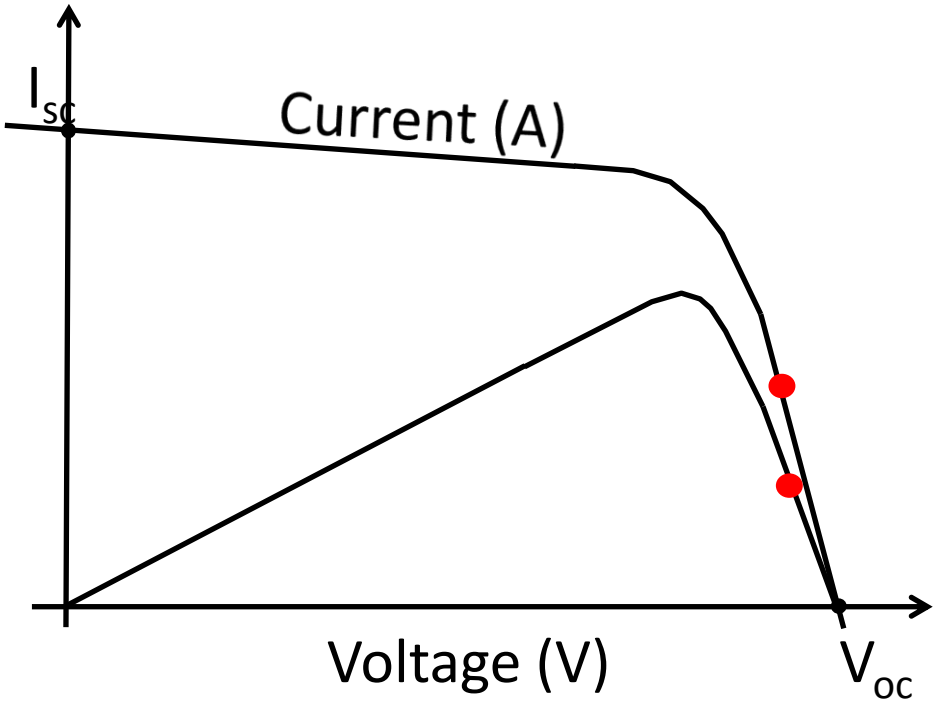



- DC/AC Ratios have been climbing in new PV installations (~125%)
- High DC/AC Ratios can be very challenging inverter reliability environments

# Future of Inverter Reliability
# High DC/AC Ratios




- DC/AC Ratios have been climbing in new PV installations (~125%)
- High DC/AC Ratios can be very challenging inverter reliability environments
- Inverter at maximum power, high voltage state for many hours during the day
- Lifetimes will become shorter due to high power/high voltage environments

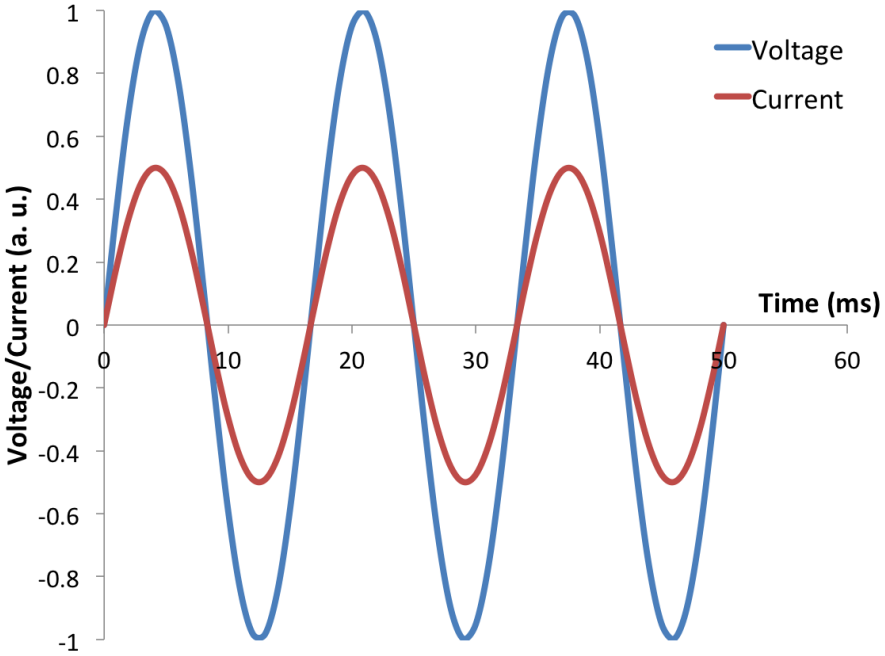
# Future of Inverter Reliability
# VAR Support

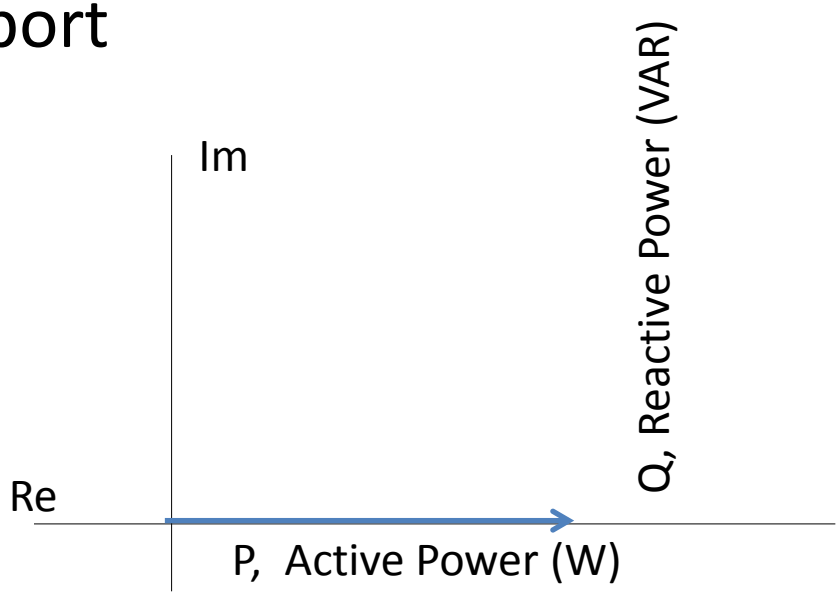
Alternating current described by a sine wave:

$$V(t) = V_p \times \sin(\omega t)$$

$$I(t) = I_p \times \sin(\omega t + f)$$

$$S(t) = I \times V \Rightarrow P\cos(\omega t) + iQ\sin(\omega t)$$




ϕ=0
Purely resistive
Voltage and Current in phase
Q=0, S=P

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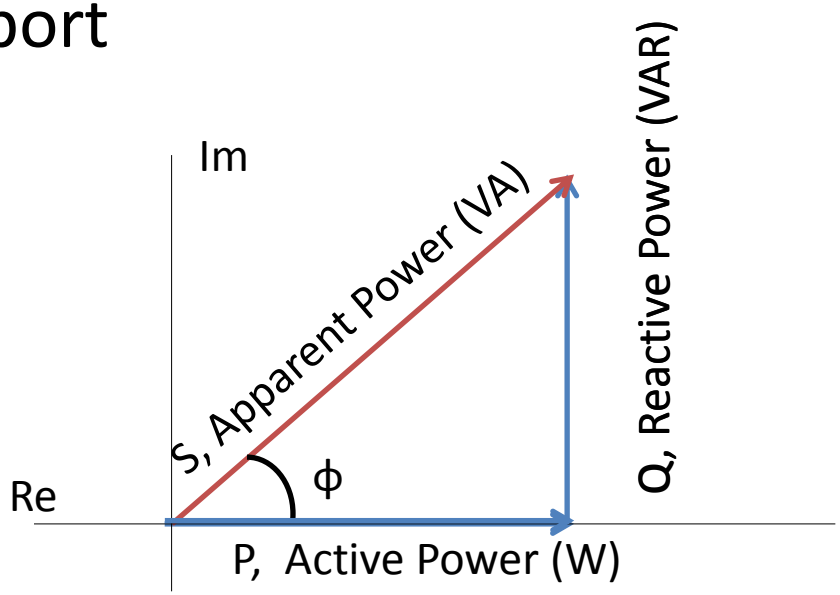


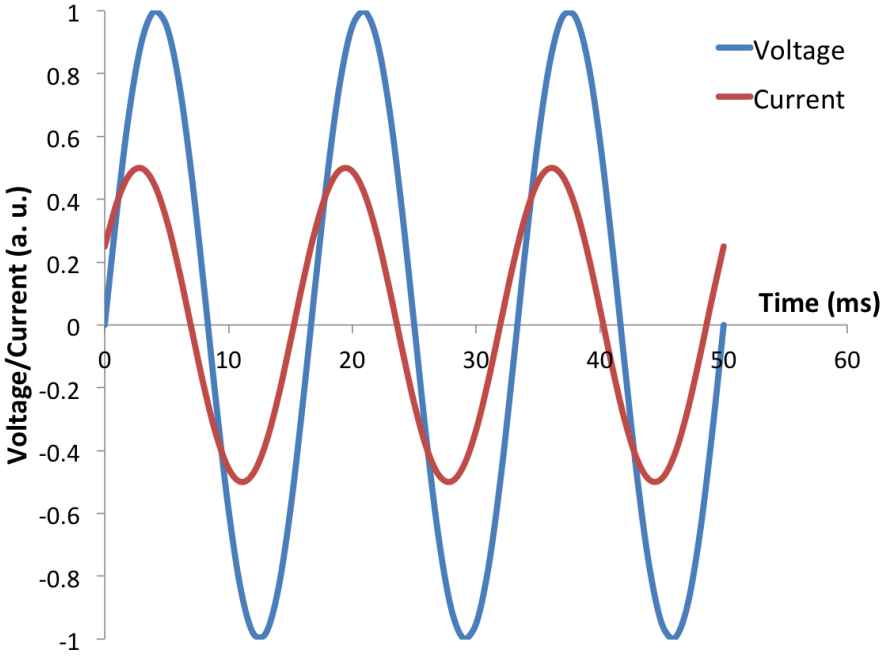


Φ>0
Capacitive System
Voltage lags Current
Q>0, Source VARs

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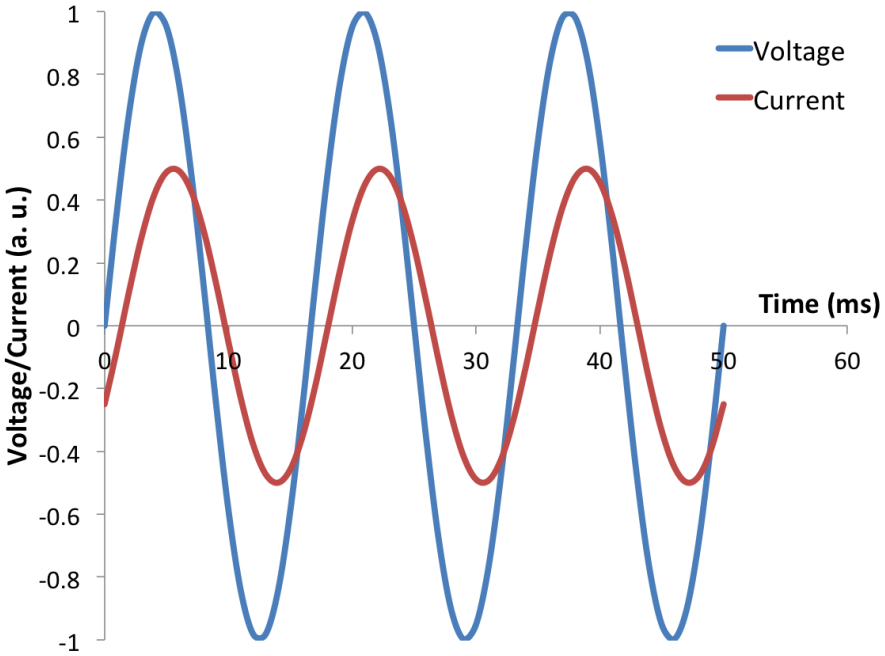
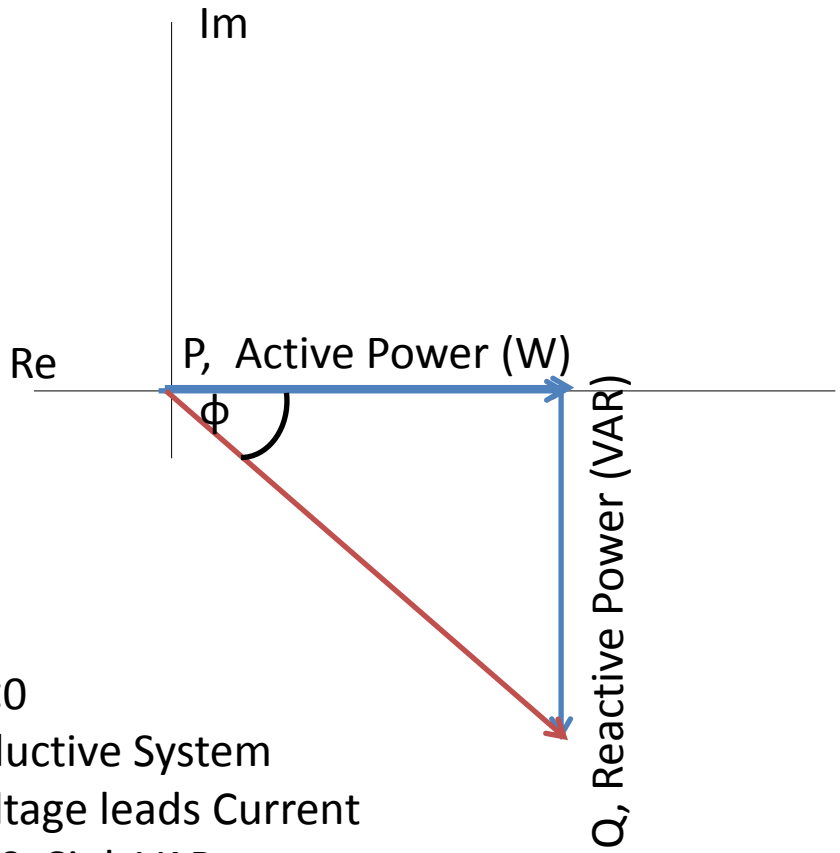


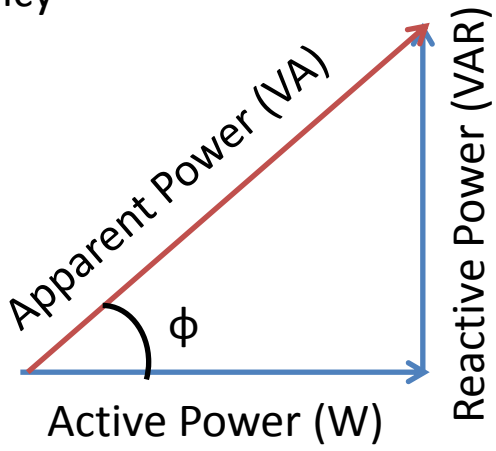




Φ<0
Inductive System
Voltage leads Current
Q<0, Sink VARs

# Future of Inverter Reliability
# VAR Support

Used to stabilize grid voltage (voltage droop or rise) and change grid power factor

- Utilities want PF≈1 because maximize active power efficiency




Many blackout events caused by **<u>unexpected</u>** hot days

- Larger usage of air conditioning units than expected
- Large inductive loads coming online causes current inrush
  - → Grid voltage decreases
  - → Grid PF moves away from 1
- Lower voltage causes higher current draw (at lower efficiencies)
  - → further decrease line voltage
- Higher current flow heats overhead line
  - → sags and shorts on a tree
  - → overloading other lines in blackout

# Future of Inverter Reliability
# VAR Support

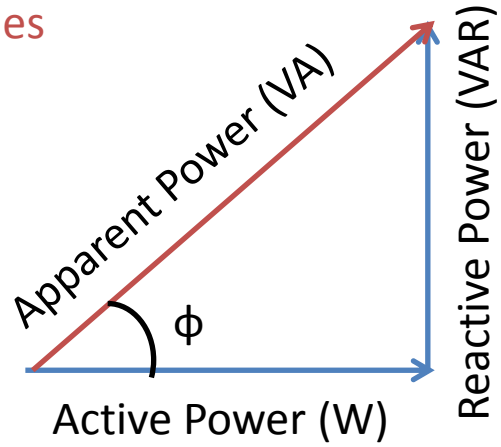
Two solutions to this problem:

1. Increase generating capacity via peaker (Natural Gas or Diesel) plants

   Slow to come online (~10 min), Expensive to operate

2. Increase grid capacitance to cancel out inductive loads (bring PF to 1, resist V droop)

   Fast, capacitor banks are expensive with reliability issues




Historically, utilities have asked inverters to disconnect from grid

- Inverters can alter ϕ easily through switching schemes
- Easily and quickly become capacitive/inductive (source/sink VARs)

Now, utilities asking inverters to stabilize the grid through VAR support

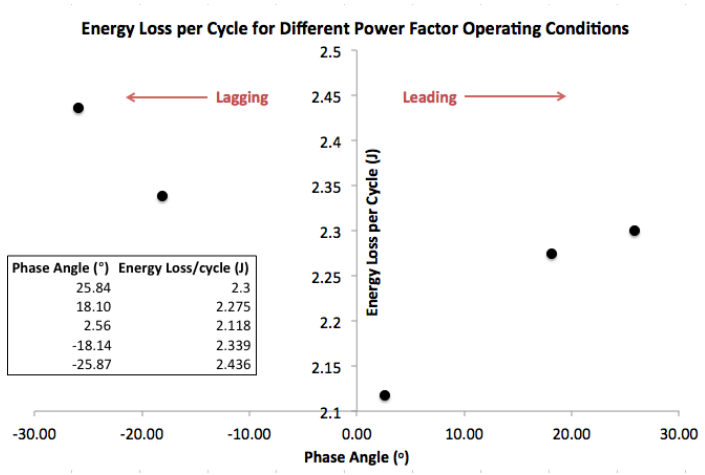
# Future of Inverter Reliability
# VAR Support

In the future, VARs may become (more) monetized

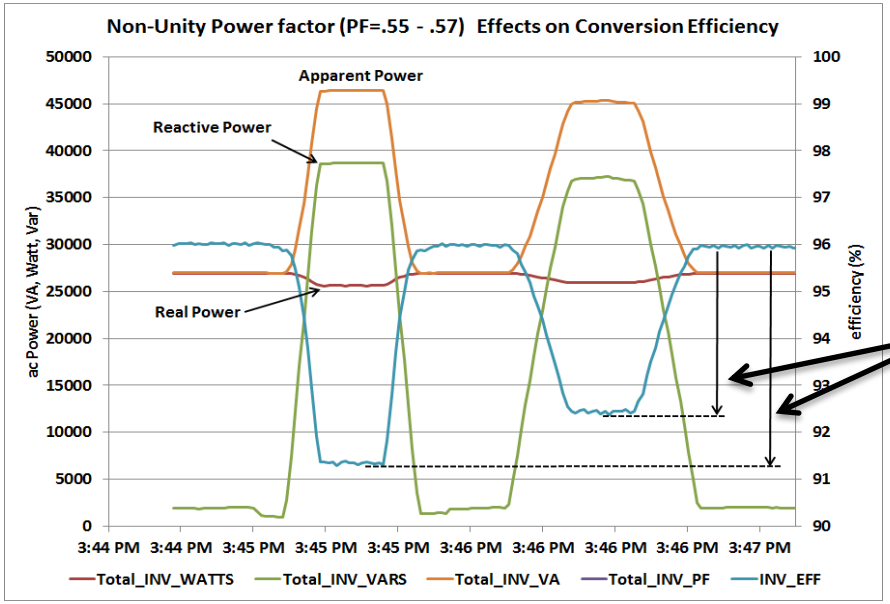
- Incentive for operators to control VARs at non-peak active power hours
- Inverters can source/sink VARs at **full power handling** of inverter during all inverter operation
- **Lower inverter efficiencies** when sourcing/sinking VARs

→Increased aging rates, more internal heating

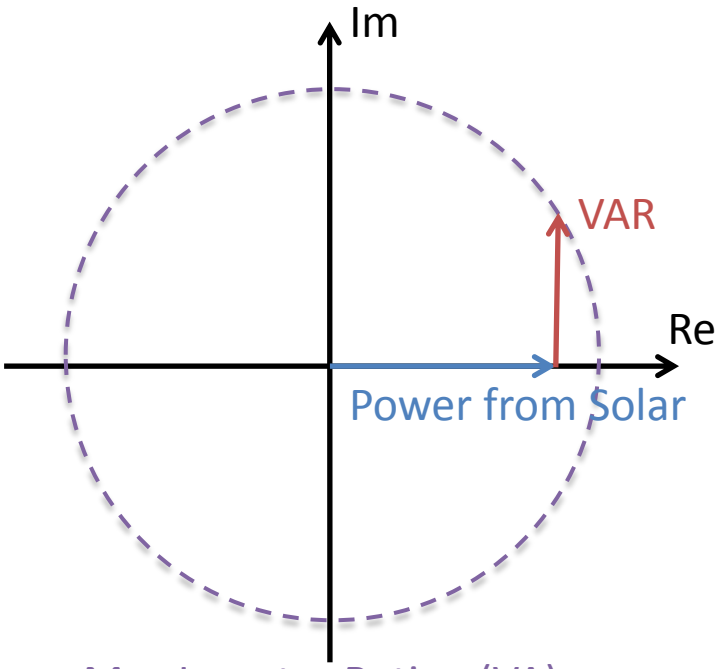
→shorter lifetimes



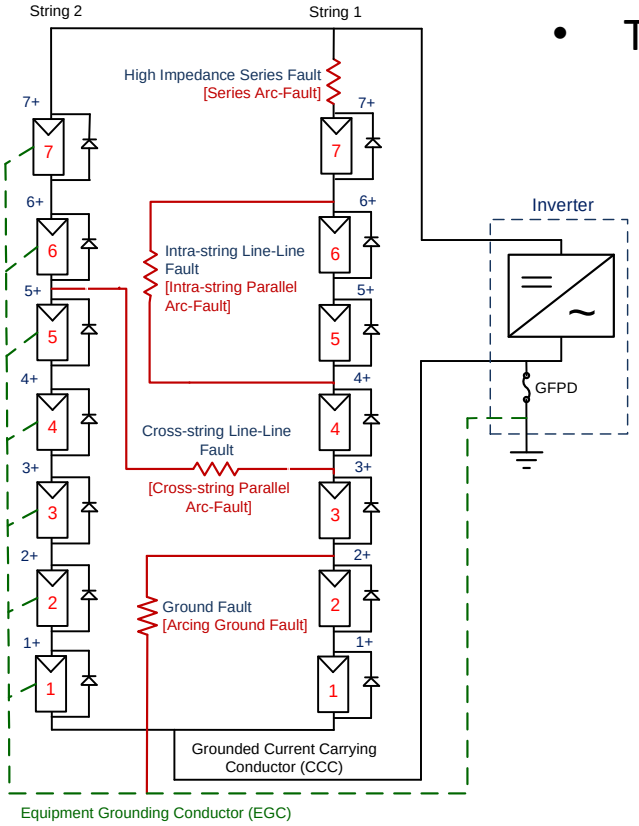

| Phase Angle (°) | Energy Loss/cycle (J) |
|---|---|
| 25.84 | 2.3 |
| 18.10 | 2.275 |
| 2.56 | 2.118 |
| -18.14 | 2.339 |
| -25.87 | 2.436 |



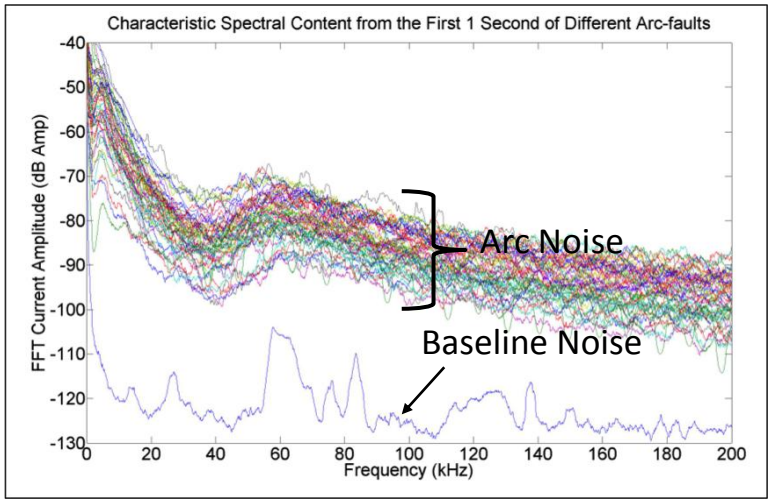

**Efficiency Decrease**



# Future of Inverter Reliability Arc/Ground Fault Location




- Types of arc-faults
  - Series Arc-Fault – Arc from discontinuity in electrical conductor (2011 *NEC* requires)
  - Parallel Arc-Fault – Electrical discharge between conductors with different potentials (2017 *NEC* ***may*** require )

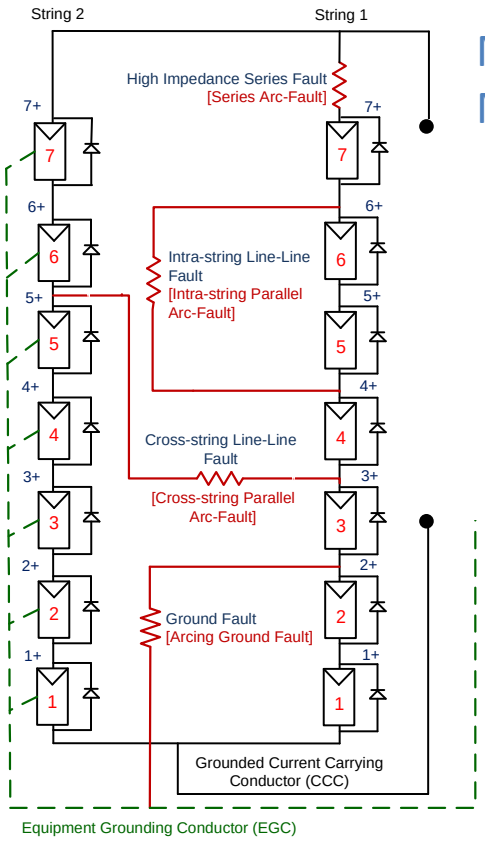



What happens ***after*** a fault is detected and cleared?

Must be located and removed

**Extremely difficult for large arrays**

# Future of Inverter Reliability
# Arc/Ground Fault Location



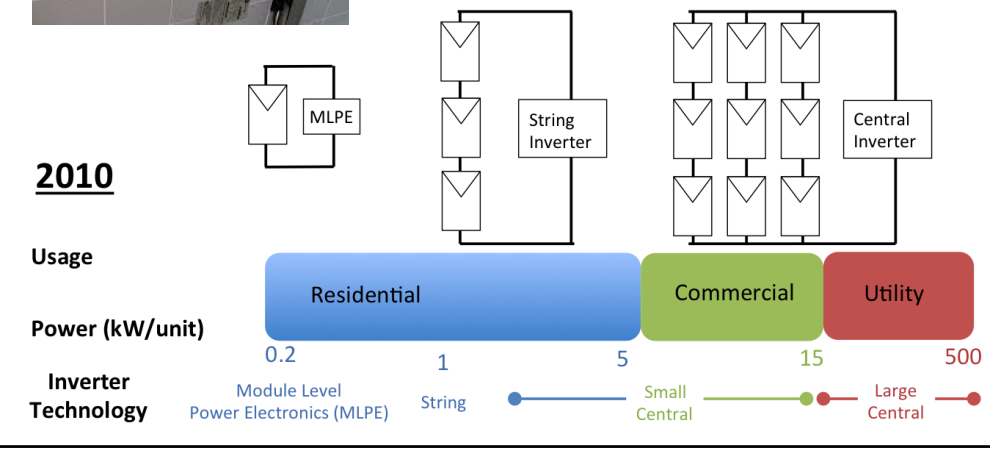

More Manual

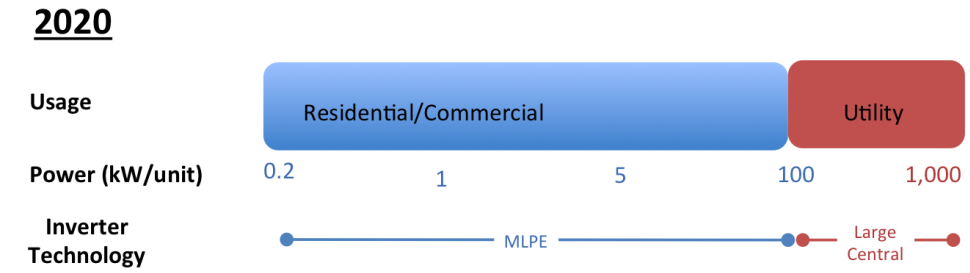
More Automatic

| | |
|---|---|
| Line Checker/Circuit Tracer | • Higher resolution<br>• Physically trace entire system ($$$) |
| String/Module Measurement | • Continuous string/module level data<br>• High resolution<br>• Sensor Intensive ($$$) |
| Numerical Techniques | Requires:<br>• Irradiance, temperature and array data<br>• Detailed electrical module characteristics<br>• No string-level accuracy |
| Earth Capacitance Measurement (ECM) | • Module-level accuracy<br>• Requires external LCR meter<br>• String-level accuracy (??) |
| Time Domain Reflectometry (TDR) | • No voltage/current measurement<br>• Sensitive to connection degradation (prognostics)<br>Requires:<br>• External signal generator<br>• High speed sampling<br>• Previous baseline<br>• Difficult analysis<br>• String-level accuracy (??) |

Can these detection/location methods be used for parallel faults as well?

# Future of Inverter Reliability Microinverter/Microconverters




## MLPE Advantages:

-Safety (reduced arc fault danger)
-Failures result in less energy loss
-Higher energy yield(module-level IV)
-Increased component lifetime

MLPEs in large-scale production <10 yrs

-no long term lifetime data
-unknown if MLPEs can last 25 yrs in field
-DOE PREDICTS for reliability standard

## MLPE Disadvantages:

-Subjected to more extreme environments (especially if close to the PV module)
-Large number of devices is reliability/O&M issue
-Customers demand same warranty period as associated module (25 yrs)
- Challenging for power handling device

# Acknowledgements

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